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Air contamination of households versus hospital inpatient rooms occupied by SARS-CoV-2 positive patients

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Abstract

Households are settings with some of the highest COVID-19 secondary-attack-rates. We compared the air contamination in hospital rooms versus households of COVID-19 patients. Inpatient air-samples were only positive at 0.3 meters from patients. Household air samples were positive even without a COVID-19 patient in the proximity to the air sampler.

Introduction

SARS-CoV-2 is transmitted primarily by respiratory droplets and contact with contaminated surfaces and fomites.[1] Airborne transmission is still a controversial topic among the scientific community. A few studies have successfully identified SARS-CoV-2 in the air of hospital rooms using real-time reverse transcriptase polymerase chain reaction (RT-PCR) or viral cultures.[2-5] However, air contamination in households has yet to be characterized. Households are settings with high secondary attack rates; members of the same household have been shown to experience up to ten times greater risk of COVID-19 than other contacts (i.e., healthcare workers, workplace contacts, and non-household contacts). [6-8]

Understanding the degree of air contamination in household settings would help us tailor prevention interventions in these high risk settings. To address this knowledge gap, our study aimed to characterize and compare the presence of SARS-CoV-2 in air samples obtained in household settings against air samples obtained in inpatient rooms both selected based on the presence of SARS-CoV-2 positive patients.

Methods

This study was performed at Froedtert Memorial Lutheran Hospital, a 607-bed academic medical center affiliated with the Medical College of Wisconsin. This inpatient facility has 6 intensive care units (ICU) with 150 ICU beds. During the pandemic, a few units were designated for cohorting SARS-CoV-2 positive patients, including the medical ICU, the cardiovascular ICU, and a couple of general medical/surgical units. All these units were set to at least 6 air changes per hour and at negative pressure relative to the hallways.

A convenience sample of rooms was selected based on the presence of patients with positive SARS-CoV-2 RT-PCR test. Households were identified based on the presence of a at least one household member with symptoms compatible with COVID-19 and at least one positive SARS-CoV-2 RT-PCR test. All subjects had to have a positive SARS-CoV-2 test in the preceding 7 days from air sampling.

Air sampling and molecular testing: Air samples were collected using the Sartorius MD8 airscan sampling device (SartoriusAG, Germany) with sterile gelatin filters (80 mm in diameter and 3 μm pore size (SartoriusAG, Germany). Briefly, the air sampler was positioned 0.305-1.83 m from the patient's head to collect from 1,000 L to 4,000 L (50 L/min). We evaluated shorter distances and higher volumes until we were able to detect SARS-CoV-2 in air samples. For samples that obtained 4,000 liters, two air samplers were used concomitantly for 40 minutes (50 L/min; 2000 L each). Gelatin filters were placed in 6 mL of viral transport media (VTM) (Remel M4RT, ThermoFisher, Lenexa, KS). If two air samplers were used concomitantly to achieve 4,000 L, then both gelatin membranes were placed in a single container with 6 mL of VTM. These plates were incubated at 37^{o}C for one minute to allow the gelatin filter to dissolve. This mixture was then vortexed and centrifuged at 13,000×g for 1 minute, and 1 mL of the supernatant was used for nucleic acid extraction. Nucleic acid

extraction and RT-PCR was performed on the Cobas 6800 (Roche, Indianapolis, IN) per the manufacturers EUA approved product insert. For patient specimens, combined nasopharyngeal and oropharyngeal swabs were collected from each patient and both the nasopharyngeal and oropharyngeal swabs were placed into 3 mL VTM (Copan, Murrieta, CA). RT-PCR was performed to detect the presence of SARS-CoV-2 on each sample using the Cobas 6800 per the manufacturers EUA approved product insert.

Results

We included 25 air samples from 15 inpatient rooms (16 samples) and 5 households (9 samples) where SARS-CoV-2 positive patients were housed (Table). Overall, 2 (12.5%; 2 inpatient rooms) out of 16 air samples from inpatient rooms were SARS-CoV-2 positive, while 5 (55.5%; 3 households) out of 9 household samples had virus detected (odds ratio: 8.75; 95% confidence interval: 1.21-63.43; p=0.058). All samples had cycle threshold levels above 30.

Hospital air samples: Out of 15 patient rooms sampled, 14 were located in COVID units (5 in ICUs and 9 in general medicine wards) and 1 on a non-COVID unit. All rooms were set to have at least 6 air changes per hour, with negative pressure relative to the hallway, and their median square size was 260.1 m^2 (range 89.2-260.1). Out of 15 air samples, 7 sampled 1,000 liters (ranging from 1.83 to 0.91 meters from the patient), being all of these samples negative. Five samples tested 2,000 liters at 0.91 meters from the patient (all SARS-CoV-2 negative), 2 samples tested 4,000 liters at 0.91 meters (all SARS-CoV-2 negative), and 2 patients were sampled using 4,000 liters each at 0.30 meters[9] from the patient (both SARS-CoV-2 positive) (Supplementary Figure 1 and Table).

Regarding the characteristics of the 15 inpatients housed within the rooms sampled: 5 (33%) had hypoxic respiratory failure, 4 (26.6%) had COVID-19 pneumonia, 3 (20%) had fever with respiratory symptoms, two (13.3%) were asymptomatic, and one (6.6%) had septic shock of unclear etiology (Table). Two-third of patients required oxygen support at the time of sampling: 2 (13.3%) were mechanically intubated, 2 (13.3%) were on bilevel positive airway pressure, 3 (20%) were on high flow nasal cannula, and 4 (26.6%) on nasal cannula. The median number of days from symptom onset to air sampling was 5 (range 2.75-8.5). The median number of days from the last positive SARS-CoV-2 test to the day of air sampling was 1.5 (range 1-3.75). The two patients occupying the rooms with positive air samples had mild severity of illness and were not on supplemental oxygen. Days from symptom onset to sampling were 5 (patient 14) and 3 (patient 15).

Household air samples: All five households had at least one symptomatic SARS-CoV-2 positive member at the time of sampling, being none of these patients on supplemental oxygen. All positive household members had respiratory symptoms at the time of air sampling. The median number of days from the last positive SARS-CoV-2 test to the day of air sampling was 3 (range 2.5-5). Five samples (55.5%) from 3 households were positive for SARS-CoV-2 (Supplementary Figure 2). Only one household had air conditioning running (#20) and 3 households had opened windows or doors inmmediately prior to air sampling (#17, #16, #19). Anecdotally, most households felt warm and humid at the time of testing.

Discussion

In this study, household samples were eight times more likely to test positive for the virus than inpatient samples. Inpatient rooms only tested positive when the volume of air sampled was quadrupled and the distance between air samplers and patients was minimal. Thus, these positive results may represent contaminated respiratory droplets being expelled by patients

rather than actual air contamination. Given that room ventilation (i.e., air changes per hour) was the main difference between these settings, our findings may suggest that the degree of ventilation in a room is more important determining the degree of air contamination than the acuity of illness that a SARS-CoV-2 patient may be experiencing. Previous studies have characterized the air contamination in inpatient areas with a wide range of findings between 1.3% to 63.2%[2-5]; however, the viability of the virus in air samples is still controversial. To the best of our knowledge, this is the first report of air contamination by SARS-CoV-2 within household settings.

Our study had a small sample size, used convenience samples, and did not perform viral cultures. Further, we did not measure the temperature or humidity of the rooms, which are environmental variables that may potentially impact the viability of the virus. In addition, we obtained more air samples per household than per inpatient room; therefore, there we increased the likelihood of detecting positive samples in households. Despite of our limitations, the preliminary findings presented suggest that household settings may have high degree of air contamination, signaling a major impact of room ventilation on this outcome. Future studies should characterize the variables determining the degree of air contamination in households and explore innovative ways to ameliorate this, especially in crowded households without access to natural ventilation.

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Conflic of interest

All authors report no conflicts of interests related to this publication.

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Table. Presence of SARS-CoV-2 in households and inpatient hospital rooms occupied by occupied by SARS-CoV-2 positive patients.

Patient / Household	Unit/ Room	Windows opened prior to testing	Air conditioning or fans on	COVID-19 symptoms on day of testing	Date of symptoms onset	Date of admission	Oxygen requirement	Last SARS-CoV-2 positive test	Date of sampling	Sampling time (minutes)	Air volume sampled (liters)	Distance from patient (meters)	Approximate cubic size of room (meters)	RT-PCR result of air sample	CT values for air samples
1	COVID unit (General Medicine)	NA	NA	No COVID-19 symptoms	NA	8/16/20	No	8/16/20	8/19/20	20	1000	1.83	260.1	Negative	NA
2	COVID unit (General Medicine)	NA	NA	Pneumonia	8/13/20	8/16/20	High flow nasal cannula	8/16/20	8/19/20	20	1000	1.83	260.1	Negative	NA
3	COVID unit (General Medicine)	NA	NA	No COVID-19 symptoms	NA	8/14/20	No	8/15/20	8/19/20	20	1000	1.83	260.1	Negative	NA
4	COVID unit (ICU)	NA	NA	Hypoxic respiratory	8/18/20	8/19/20	BiPAP	8/19/20	8/26/20	20	1000	0.91	89.2	Negative	NA

				failure											
5	COVID unit (ICU)	NA	NA	Hypoxic respiratory failure	8/10/20	8/16/20	High flow nasal cannula	8/14/20	8/26/20	20	1000	0.91	89.2	Negative	NA
6	Non-COVID unit (ICU)	NA	NA	Septic shock unclear etiology	Unknown	8/21/20	Intubated	8/21/20	8/26/20	20	1000	0.91	157	Negative	NA
7	COVID unit (General Medicine)	NA	NA	Hypoxic respiratory failure	Unknown	9/2/20	Nasal Cannula	9/2/20	9/4/20	20	1000	0.91	260.1	Negative	NA
7	COVID unit (General Medicine)	NA	NA	Hypoxic respiratory failure	Unknown	9/2/20	Nasal Cannula	9/2/20	9/4/20	40	2000	0.91	260.1	Negative	NA
8	COVID unit	NA	NA	Hypoxic respiratory	9/4/20	8/25/20	No	9/8/20	9/9/20	40	2000	0.91	260.1	Negative	NA

	(General Medicine)			failure										
9	COVID unit (General Medicine)	NA	NA	Hypoxic respiratory failure	9/7/20	9/8/20	High flow nasal cannula	9/8/20	9/9/20	40	2000	0.91	260.1	Negative	NA
10	COVID unit (General Medicine)	NA	NA	Pneumonia	9/5/20	9/1/20	Nasal Cannula	9/8/20	9/9/20	40	2000	0.91	260.1	Negative	NA
11	COVID unit (ICU)	NA	NA	Pneumonia	9/7/20	9/6/20	Intubated	9/8/20	9/9/20	40	2000	0.91	89.2	Negative	NA
12	COVID unit (ICU)	NA	NA	Cough, fatigue, fever, diarrhea	9/12/20	9/21/20	Nasal Cannula	9/22/20	9/22/20	40	4000	0.91	89.2	Negative	NA
13	COVID unit (ICU)	NA	NA	Pneumonia	Unknown	9/21/20	Nasal Cannula	9/21/20	9/22/20	40	4000	0.91	89.2	Negative	NA

14	COVID unit (General Medicine)	NA	NA	Chest pain, cough, shortness of breath	9/30/20	10/4/20	No	10/4/20	10/5/20	**40**	**4000**	**0.30**	260.1	**Positive**	33.04
15	COVID unit (General Medicine)	NA	NA	Fever, shortness of breath, cough	10/2/20	10/4/20	No	10/4/20	10/5/20	**40**	**4000**	**0.30**	260.1	**Positive**	36.27
16	Household - bedroom	Yes	No	Respiratory symptoms, fatigue	NA	NA	No	10/5/20	10/7/20	**40**	**2000**	**0.91**	156.1	**Positive**	36.1
16	Household - bedroom	Yes	No	Respiratory symptoms, fatigue	NA	NA	No	10/5/20	10/7/20	**40**	**2000**	**1.83**	156.1	**Positive**	37.43
17	Household - bedroom	No	No	Respiratory symptoms, fatigue	NA	NA	No	10/5/20	10/8/20	20	1000	0.91	136.6	Negative	NA
17	Household - tv room	Yes	No	Respiratory symptoms,	NA	NA	No	10/5/20	10/8/20	20	1000	0.91	53.5	Negative	NA

				fatigue											
18	Household - kitchen	No	No	Respiratory, loss of taste/smell	NA	NA	No	10/1/20	10/8/20	**20**	**1000**	**0.91**	53.5	**Positive**	37.65
18	Household - living room	No	No	Respiratory, loss of taste/smell	NA	NA	No	10/1/20	10/8/20	**20**	**1000**	**NA***	66.9	**Positive**	37.52
19	Household - bedroom	Yes	No	Respiratory symptoms	NA	NA	No	10/6/20	10/9/20	20	1000	NA*	47.6	Negative	NA
19	Household - tv room	Yes	No	Respiratory symptoms	NA	NA	No	10/6/20	10/9/20	20	1000	0.91	74.3	Negative	NA
20	Household - bedroom	No	Yes	Respiratory symptoms, fatigue	NA	NA	No	8/3/20	8/6/20	**20**	**1000**	**1.83**	89.2	**Positive**	37

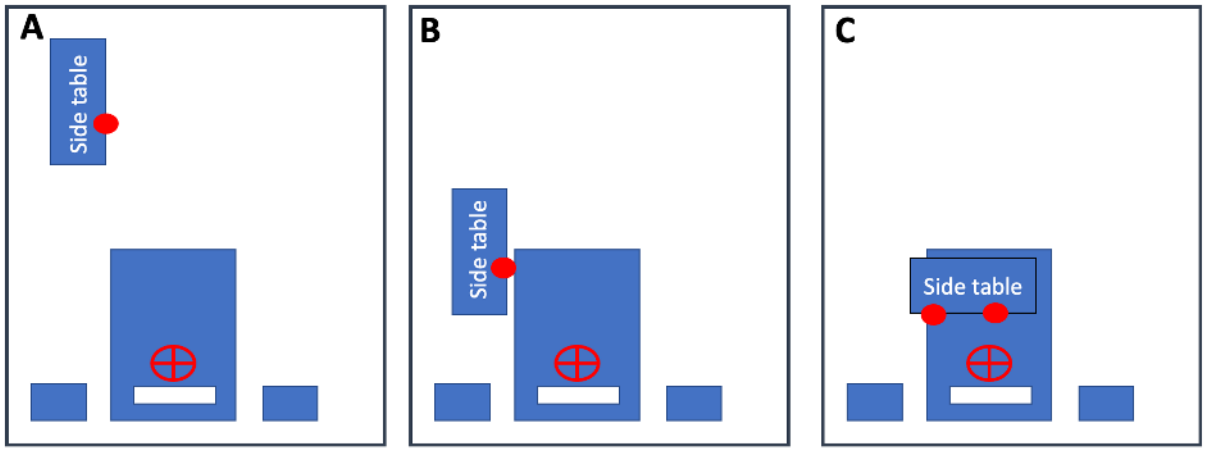
ICU: Intensive Care Unit. NA: Not applicable. RT-PCR: reverse transcriptase-polymerase chain reaction. CT: cycle threshold. BiPAP: bilevel positive airway pressure.

*No positive patient was present in the room.

Supplementary Figure 1.

Title: Layout of hospital rooms designated for COVID-19 patients and position of air samplers.

Legend: The air sampler was placed on the side table at A) 6 feet and B) 3 feet from the patient. C) Two air samplers were run at one foot from the patient's face. Red circle: air sampler; Red cross: patient's face. Horizontal surfaces are depicted in blue.



Supplementary Figure 2.

Title: Household settings positive for SARS-CoV-2.

Legend: A) Household 16: the two positive samples were collected from the same room at 3 and 6 feet from the patient; B) Household 18 had positive samples in the living room and the kitchen; symptomatic children were running around the household at the time of collections (dotted line), but no one was in close proximity to the air sampler placed in the living room. The kitchen air sampler ran while one of the symptomatic adults cooked. C) Household 20: the air sample was obtained while the symptomatic patient talked on her cellphone during sampling. Red circle: air sampler; Red cross: patient's face. Horizontal surfaces are depicted in blue.